



# Efficacy of Early Cardiac Rehabilitation After Cardiac Surgery — Verification Using Japanese Diagnosis Procedure Combination Data —

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**Background:** The current status of cardiac rehabilitation (CR) after cardiac surgery and the introduction of early CR (E-CR) in Japan are not fully understood. In this study, the current status of E-CR and its efficacy were investigated by the Academic Committee of the Japanese Association of Cardiac Rehabilitation.

**Methods and Results:** We examined the rate of introduction of E-CR and its effects among 220,122 patients who underwent major cardiac and thoracic vascular surgery, as registered in the Diagnosis Procedure Combination (DPC) classification system, between April 2012 and March 2018. In this study, E-CR was defined as CR starting within 1 day after surgery. Patients with and without E-CR were propensity score matched and analyzed for clinical outcomes. Of all patients participating in CR after surgery, E-CR was initiated in 52.1%, 56.9%, 47.4%, and 54.1% of patients undergoing coronary artery bypass grafting, valve surgery, aortic surgery, and other cardiovascular surgery, respectively. After propensity score matching, outcomes for E-CR were significantly superior to non-E-CR in terms of in-hospital deaths, Barthel Index score at discharge, length of hospital stay, and hospitalization costs.

**Conclusions:** E-CR after cardiac surgery was effective in terms of prognosis, hospital stay, and medical costs. This study is the first report using big data in Japan. The results indicate that further introduction of E-CR needs to be recommended in the future.

**Key Words:** Cardiac rehabilitation; Cardiac surgery; Coronary artery bypass grafting (CABG); Open surgery

Cardiac rehabilitation (CR) started in the 1960s for acute myocardial infarction<sup>1</sup> and is now used for various cardiovascular diseases, such as chronic heart failure, and after cardiac surgery. CR improves exercise tolerance, coronary risk factors and patients' quality of life (QOL), reduces cardiovascular recurrence and mortality,<sup>2,3</sup> and is a Class I recommendation in various

European, US, and Japanese guidelines.<sup>4–7</sup> In recent years, multidisciplinary interventions by physicians, nurses, dietitians, pharmacists, and other multidisciplinary team members from pre- to post-discharge has been shown to reduce readmission rates, improve QOL, and save medical costs.<sup>4</sup>

With advances in minimally invasive cardiac surgery and postoperative management, the indications for surgery

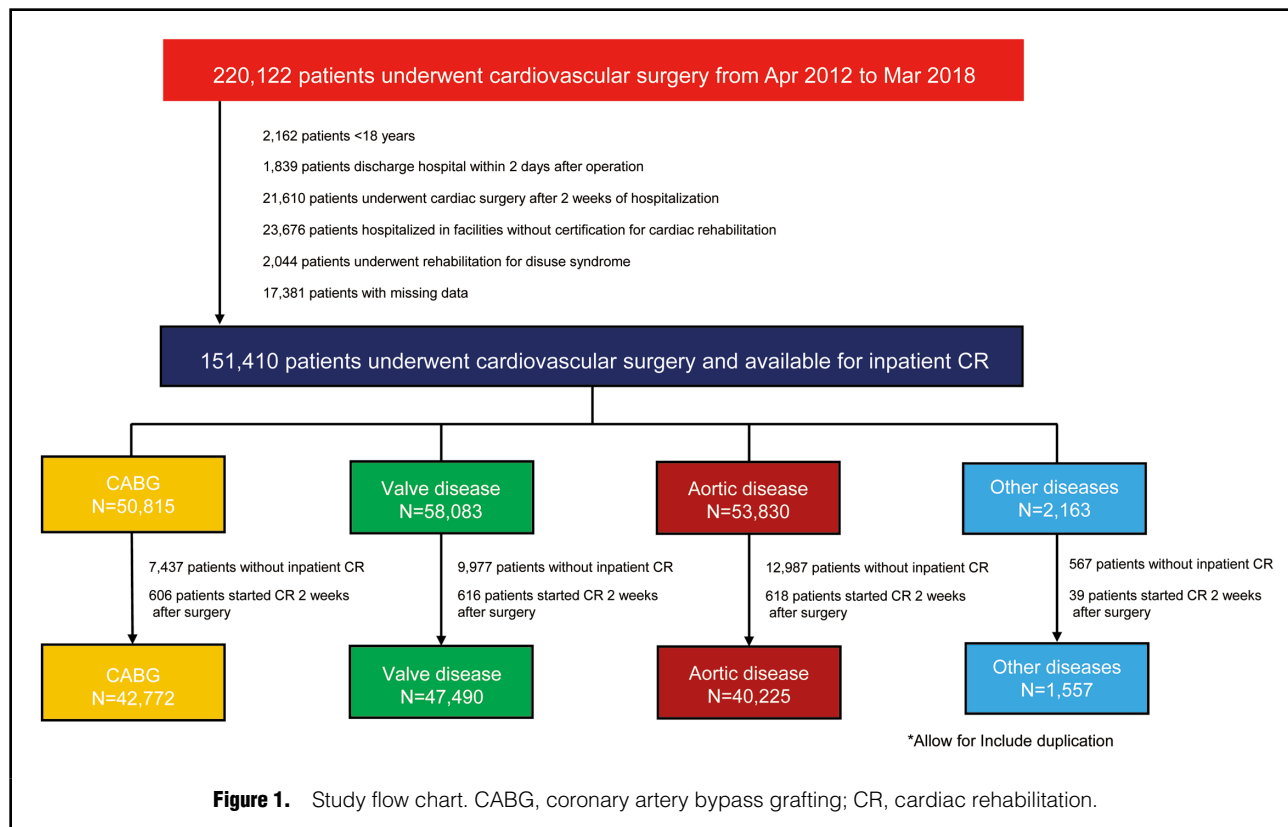
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have expanded to include high-risk and much older patients. In addition, frailty and sarcopenia have been regarded as important prognostic factors in cardiac surgery, and post-operative CR is important.<sup>8</sup> Furthermore, after cardiac surgery, CR has been shown to be effective from various aspects, such as exercise tolerance, autonomic nerve activity, cardiac and peripheral functions, QOL, psychological aspects, rehospitalization rates, and medical costs.<sup>9,10</sup> In Japan, the introduction of CR was delayed compared with Europe and the US, but reimbursement for acute myocardial infarction was approved in 1988, and the indication for CR was expanded to open heart surgery in 1996.

However, the current status of CR after cardiac surgery and the introduction of early CR (E-CR) in Japan are not fully known. Therefore, this study investigated the current status and effectiveness of E-CR in 220,122 patients who underwent cardiac and thoracic aortic surgery, as registered in the Diagnosis Procedure Combination (DPC) classification system, between April 2012 and March 2018. In addition, the effectiveness of E-CR was investigated by the Academic Committee of the Japanese Association for Cardiac Rehabilitation.

## Methods

### Source of Data

We used the Japanese Registry of All Cardiac and Vascular Diseases and DPC (JROAD-DPC) database. The JROAD-DPC is a claim database derived from the Japanese DPC/per diem payment system (PDPS), and covered over 1,000 Japanese Circulation Society (JCS)-certified training hospitals during the study period.<sup>11,12</sup> The JROAD-DPC

includes detailed patient information, such as age, sex, body mass index (BMI), Barthel Index (a performance scale of the activities of daily living [ADL]), diagnostic and comorbidity codes based on the 10th revision of the International Statistical Classification of Diseases (ICD-10) codes, therapeutic procedures, medications, hospitalization costs, and in-hospital outcomes. The JROAD-DPC database was merged with the hospital-level database (JROAD), which includes hospital characteristics, such as the number of surgeons and the number of hospital beds in each hospital.<sup>13</sup>

### Study Design and Patients

This was a retrospective nationwide study that used the JROAD-DPC database. We extracted patients who underwent open surgery for cardiovascular diseases, including coronary artery diseases, valve diseases, and aortic diseases, between April 2012 and March 2018. The procedural codes for open surgery were: K539-2, K540, K544, K551, K552, K552-2, K553, K553-2, K554, K554-2, K555, K555-2, K555-3, K556, K557, K557-2, K557-3, K557-4, K558, K559, K560, K560-2, K577, K592, K592-2, K593. We included adult patients who underwent open surgery and were eligible for inpatient CR in the early phase after surgery. Patients meeting the following criteria were excluded: age <18 years; discharged from hospital within 2 days after the operation; undergoing open surgery after 2 weeks of hospitalization; hospitalized in facilities that were not CR certified; (5) undergoing rehabilitation for disuse syndrome; and (6) missing data.

We focused on the timing of the start of CR after open surgery. Of all patients who were eligible for E-CR, those who did not participate in CR and those who started CR

2 weeks after open surgery were excluded from this study. The patients included in the study were categorized into 2 groups (E-CR and non-E-CR) by the median number of days after open surgery when CR was started.

The association between E-CR and non-E-CR and each outcome was analyzed according to the category of open

surgery. All patients eligible for inpatient CR were divided into 4 groups using the following surgical categories: coronary artery bypass grafting (CABG); valve disease (patients underwent open-heart surgery for valvular heart diseases); aortic disease (patients underwent open-heart surgery for aortic diseases such as aortic aneurysm and acute aortic

| <b>Table 1. Baseline Characteristics in Patients Undergoing CABG, Valve Surgery, Aortic Surgery or Other CV Surgery</b> |               |                      |                       |              |
|---|---------------|----------------------|-----------------------|--------------|
|   | <b>CABG</b>   | <b>Valve surgery</b> | <b>Aortic surgery</b> | <b>Other</b> |
| <b>No. patients</b>   | 42,772        | 47,490               | 40,225                | 1,557        |
| <b>Age (years)</b>  | 71 [64–77]    | 72 [64–78]           | 70 [63–77]            | 68 [59–75]   |
| <b>Female sex</b>   | 10,084 (23.6) | 21,573 (45.4)        | 11,703 (29.1)         | 864 (55.5)   |
| <b>BMI (kg/m<sup>2</sup>)</b>   |               |                      |                       |              |
| <18.5   | 2,280 (5.3)   | 5,277 (11.1)         | 2,988 (7.4)           | 149 (9.6)    |
| 18.5–24.9   | 26,450 (61.8) | 30,825 (64.9)        | 24,773 (61.6)         | 1,007 (64.7) |
| 25.0–29.9   | 11,826 (27.6) | 9,649 (20.3)         | 10,551 (26.2)         | 335 (21.5)   |
| ≥30.0   | 2,216 (5.2)   | 1,739 (3.7)          | 1,913 (4.8)           | 66 (4.2)     |
| <b>CCI</b>  | 2 [1–3]       | 1 [1–2]              | 2 [1–2]               | 1 [1–2]      |
| <b>BIS at admission</b>   |               |                      |                       |              |
| ≤90   | 3,812 (8.9)   | 3,960 (8.3)          | 2,407 (6.0)           | 159 (10.2)   |
| >90   | 32,802 (76.7) | 40,661 (85.6)        | 28,174 (70.0)         | 1,214 (78.0) |
| Missing   | 6,158 (14.4)  | 2,869 (6.0)          | 9,644 (24.0)          | 184 (11.8)   |
| <b>Emergency admission (%)</b>  | 11,299 (26.4) | 5,339 (11.2)         | 14,138 (35.1)         | 451 (29.0)   |
| <b>Ambulance use (%)</b>  | 6,318 (14.8)  | 2,464 (5.2)          | 10,545 (26.2)         | 197 (12.7)   |
| <b>ICU or HCU</b>   | 38,424 (89.8) | 42,987 (90.5)        | 34,757 (86.4)         | 1,421 (91.3) |
| <b>Japan Coma Scale at admission</b>  |               |                      |                       |              |
| Alert   | 41,625 (97.3) | 46,744 (98.4)        | 37,739 (93.8)         | 1,501 (96.4) |
| Dizziness   | 720 (1.7)     | 518 (1.1)            | 1,509 (3.8)           | 31 (2.0)     |
| Somnolence  | 168 (0.4)     | 104 (0.2)            | 437 (1.1)             | 11 (0.7)     |
| Coma  | 259 (0.6)     | 124 (0.3)            | 540 (1.3)             | 14 (0.9)     |
| <b>Length of stay until surgery</b>   | 4 [2–7]       | 4 [2–6]              | 2 [1–4]               | 3 [2–6]      |
| <b>CV risk factors</b>  |               |                      |                       |              |
| Heart failure   | 15,754 (36.8) | 24,734 (52.1)        | 9,774 (24.3)          | 602 (38.7)   |
| Aortic stenosis   | 6,919 (16.2)  | 28,481 (60.0)        | 8,723 (21.7)          | 66 (4.2)     |
| Endocarditis  | 143 (0.3)     | 1,551 (3.3)          | 191 (0.5)             | 17 (1.1)     |
| <b>Comorbidities (%)</b>  |               |                      |                       |              |
| Atrial fibrillation   | 3,711 (8.7)   | 11,688 (24.6)        | 3,538 (8.8)           | 233 (15.0)   |
| CKD or HD   | 7,038 (16.5)  | 5,851 (12.3)         | 3,190 (7.9)           | 100 (6.4)    |
| Diabetes  | 14,658 (34.3) | 7,122 (15.0)         | 3,417 (8.5)           | 214 (13.7)   |
| CVD   | 990 (2.3)     | 1,079 (2.3)          | 1,091 (2.7)           | 79 (5.1)     |
| PAD   | 2,643 (6.2)   | 1,217 (2.6)          | 1,638 (4.1)           | 41 (2.6)     |
| COPD  | 908 (2.1)     | 1,010 (2.1)          | 1,495 (3.7)           | 38 (2.4)     |
| Malignant diseases  | 1,352 (3.2)   | 1,295 (2.7)          | 1,405 (3.5)           | 219 (14.1)   |
| Dementia  | 273 (0.6)     | 363 (0.8)            | 354 (0.9)             | 6 (0.4)      |
| <b>Medications (%)</b>  |               |                      |                       |              |
| ACEI/ARBs   | 19,899 (46.5) | 22,620 (47.6)        | 19,349 (48.1)         | 346 (22.2)   |
| β-blockers  | 34,462 (80.6) | 34,502 (72.7)        | 26,426 (65.7)         | 820 (52.7)   |
| MRA   | 22,412 (52.4) | 31,478 (66.3)        | 16,366 (40.7)         | 856 (55.0)   |
| CCB   | 38,585 (90.2) | 42,288 (89.0)        | 37,833 (94.1)         | 1,255 (80.6) |
| Statins   | 29,124 (68.1) | 16,149 (34.0)        | 12,952 (32.2)         | 340 (21.8)   |
| HG  | 14,658 (34.3) | 7,122 (15.0)         | 3,417 (8.5)           | 214 (13.7)   |
| Loop diuretics  | 34,970 (81.8) | 42,100 (88.7)        | 31,052 (77.2)         | 1,342 (86.2) |
| Amiodarone  | 3,679 (8.6)   | 5,442 (11.5)         | 1,986 (4.9)           | 76 (4.9)     |
| Digoxin   | 1,035 (2.4)   | 2,781 (5.9)          | 761 (1.9)             | 59 (3.8)     |
| NE before surgery   | 1,234 (2.9)   | 834 (1.8)            | 317 (0.8)             | 20 (1.3)     |
| DOA before surgery  | 622 (1.5)     | 520 (1.1)            | 148 (0.4)             | 16 (1.0)     |
| DOB before surgery  | 661 (1.5)     | 892 (1.9)            | 81 (0.2)              | 14 (0.9)     |

(Table 1 continued the next page.)

|                                 | CABG          | Valve surgery | Aortic surgery | Other        |
|---------------------------------|---------------|---------------|----------------|--------------|
| <b>Device use (%)</b>           |               |               |                |              |
| Respirator before surgery       | 1,045 (2.4)   | 1,067 (2.2)   | 270 (0.7)      | 22 (1.4)     |
| IABP before surgery             | 2,522 (5.9)   | 456 (1.0)     | 20 (<1)        | 2 (0.1)      |
| ECMO before surgery             | 38 (0.1)      | 39 (0.1)      | 2 (<1)         | 10 (0.6)     |
| <b>Postoperative MCS</b>        | 6,368 (14.9)  | 2,037 (4.3)   | 338 (0.8)      | 61 (3.9)     |
| <b>Nutrition counseling</b>     | 22,350 (52.3) | 24,289 (51.1) | 17,691 (44.0)  | 631 (40.5)   |
| <b>Hospital characteristics</b> |               |               |                |              |
| JCS-certified hospital          | 42,355 (99.0) | 47,127 (99.2) | 39,785 (98.9)  | 1,547 (99.4) |
| No. hospital beds               |               |               |                |              |
| ≤300                            | 3,257 (7.6)   | 3,379 (7.1)   | 2,648 (6.6)    | 75 (4.8)     |
| 301–600                         | 13,179 (30.8) | 14,197 (29.9) | 12,774 (31.8)  | 431 (27.7)   |
| ≥601                            | 26,336 (61.6) | 29,914 (63.0) | 24,803 (61.7)  | 1,051 (67.5) |
| No. surgeons                    |               |               |                |              |
| ≤3                              | 17,749 (41.5) | 17,691 (37.3) | 15,066 (37.5)  | 567 (36.4)   |
| ≥4                              | 25,023 (58.5) | 29,799 (62.7) | 25,159 (62.5)  | 990 (63.6)   |

Data are given as the mean±SD, median [interquartile range], or n (%). ACEI, angiotensin-converting enzyme inhibitor; ARB, angiotensin receptor blocker; BIS, Barthel index score; BMI, body mass index; CABG, coronary artery bypass grafting; CCB, calcium channel blocker; CCI, Charlson comorbidity index; CKD, chronic kidney disease; COPD, chronic obstructive pulmonary disease; CV, cardiovascular; CVD, cerebrovascular disease; DOA, dopamine; DOB, dobutamine; ECMO, extracorporeal membrane oxygenation; HCU, high care unit; HD, hemodialysis; HG, hypoglycemic agents; IABP, intra-aortic balloon pumping; ICU, intensive care unit; JCS, Japanese Circulation Society; MCS, mechanical circulatory support; MRA, mineralocorticoid receptor antagonist; NE, norepinephrine; PAD, peripheral arterial disease.

**Table 2. Crude Endpoints in Patients Undergoing CABG, Valve Surgery, Aortic Surgery or Other CV Surgery**

|  | CABG          |               |         | Valve surgery |               |         |
|--|---------------|---------------|---------|---------------|---------------|---------|
|  | E-CR–         | E-CR+         | P value | E-CR–         | E-CR+         | P value |
| No. patients                                 | 20,472        | 22,300        |         | 20,457        | 27,033        |         |
| In-hospital deaths                           | 710 (3.4)     | 334 (1.5)     | <0.001  | 703 (3.4)     | 403 (1.5)     | <0.001  |
| BIS at discharge                             |               |               |         |               |               |         |
| All patients                                 | 91±23         | 95±17         | <0.001  | 92±22         | 95±16         | <0.001  |
| Discharged alive                             | 95±15         | 97±12         | <0.001  | 95±14         | 97±11         | <0.001  |
| Length of hospital stay (days)               | 25 [19–33]    | 23 [18–29]    | <0.001  | 25 [19–34]    | 23 [18–29]    | <0.001  |
| Hospitalization costs (×10 <sup>6</sup> yen) | 4.3 [3.4–5.7] | 3.7 [3.1–4.9] | <0.001  | 5.1 [4.4–6.2] | 4.8 [4.2–5.6] | <0.001  |

|  | Aortic surgery |               |         | Other         |               |         |
|--|----------------|---------------|---------|---------------|---------------|---------|
|  | E-CR–          | E-CR+         | P value | E-CR–         | E-CR+         | P value |
| No. patients                                 | 21,140         | 19,085        |         | 715           | 842           |         |
| In-hospital deaths                           | 957 (4.5)      | 404 (2.1)     | <0.001  | 29 (4.1)      | 12 (1.4)      | <0.001  |
| BIS at discharge                             |                |               |         |               |               |         |
| All patients                                 | 89±26          | 94±19         | <0.001  | 90±25         | 96±17         | <0.001  |
| Discharged alive                             | 93±18          | 96±13         | <0.001  | 94±17         | 97±12         | <0.001  |
| Length of hospital stay (days)               | 25 [19–35]     | 21 [16–29]    | <0.001  | 23 [17–34]    | 21 [16–27]    | <0.001  |
| Hospitalization costs (×10 <sup>6</sup> yen) | 5.8 [3.5–7.4]  | 4.7 [2.1–6.1] | <0.001  | 3.5 [2.9–4.9] | 3.2 [2.8–3.8] | <0.001  |

Unless indicated otherwise, data are given as the mean±SD, median [interquartile range], or n (%). E-CR, early cardiac rehabilitation. Other abbreviations as in Table 1.

dissection); other diseases (patients underwent open surgery for other diseases, including cardiac tumor and pulmonary artery thrombectomy). Patients who underwent combined surgeries were registered for each operative method.

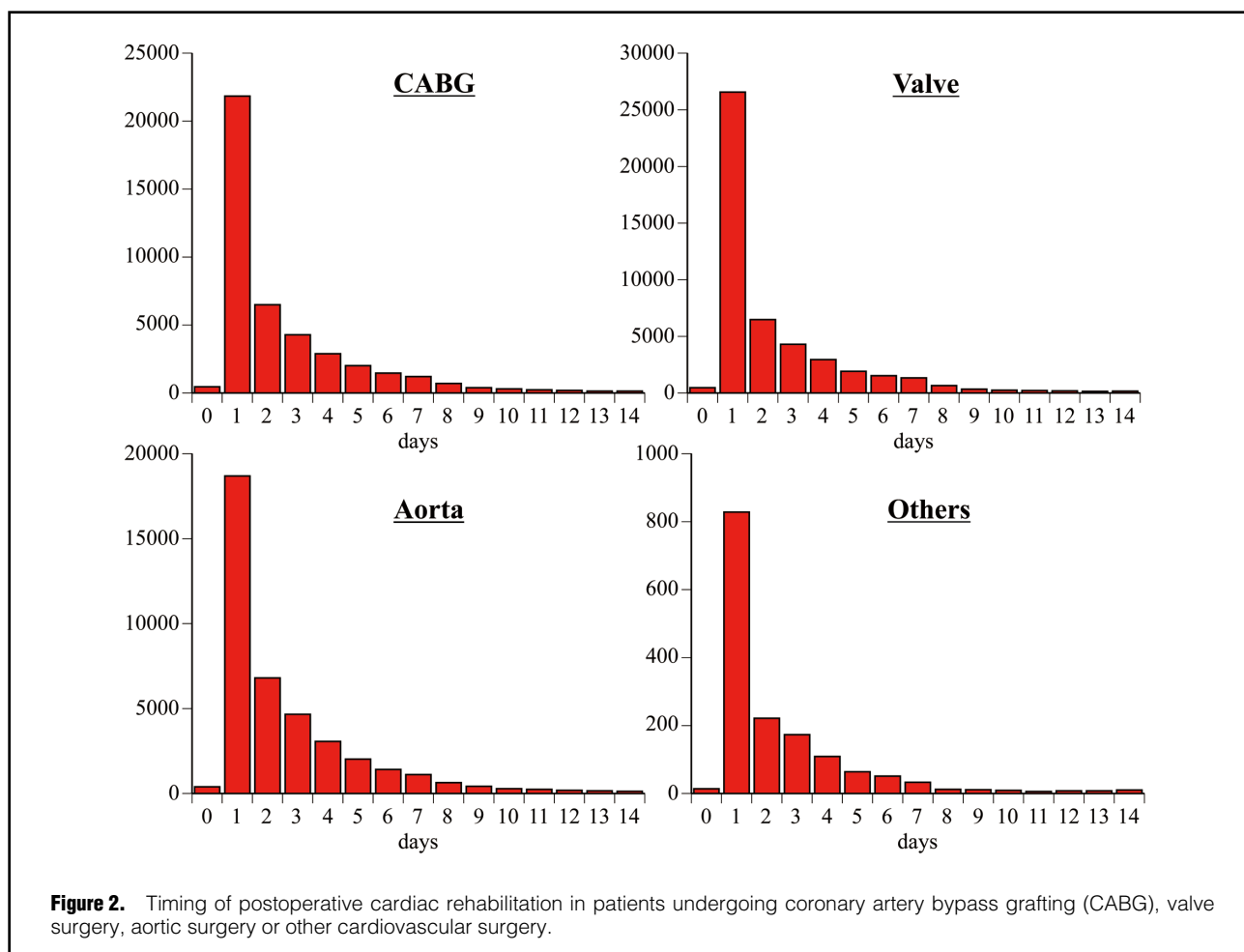
### Outcome Measures

The primary outcomes were in-hospital all-cause mortality and the Barthel Index score (BIS) at discharge. The BIS was determined as the sum of scores for all questions on the questionnaire and was analyzed as a continuous vari-

able.<sup>14</sup> Patients who died during hospitalization were assigned a BIS of 0.<sup>15,16</sup> The secondary outcomes were the length of hospital stay and the total hospitalization cost. Total hospitalization costs were calculated as the sum of bundled payments and fee-for-service payments, without the food fee.

### Statistical Analysis

Categorical variables are presented as numbers and percentages, whereas continuous variables are presented as



the mean $\pm$ SD or median with interquartile range (IQR). Comparisons between the E-CR and non-E-CR groups were made using the  $\chi^2$  test and Wilcoxon rank-sum test for categorical and continuous variables, respectively.

Propensity score matching (PSM) was used to compare outcomes between the E-CR and non-E-CR groups. Propensity scores of patients receiving E-CR or non-E-CR were generated using a multivariate logistic regression model adjusted for age, sex, BMI, Charlson comorbidity index on admission, emergency admission, cardiovascular risk factors (heart failure, aortic valve stenosis, and infective endocarditis), comorbidities (chronic kidney diseases, cerebrovascular diseases, peripheral vascular diseases, chronic obstructive lung diseases and diabetes [with oral hyperglycemic agents]), medications, and cardiopulmonary support devices before the operation. The variables used for adjustment were extracted with reference to Japan SCORE from the Japan Adult Cardiovascular Surgery Database and EuroSCORE II.<sup>17,18</sup> PSM was performed in a 1:1 ratio using nearest-neighbor matching with caliper width equal to 0.2 of the standard deviation of the logit of the propensity score without replacement. The balance between groups after PSM was assessed using the standardized difference. We analyzed associations between E-CR or non-E-CR and each endpoint using mixed-effects logistic regression models or multiple regression models with hospital as a random effect.

Sensitivity analyses were conducted using 2 additional statistical models with the same confounders to confirm the robustness of the results. First, we conducted mixed-effects logistic regression analysis for complete case (without PSM). Second, we performed inverse probability of treatment weighting (IPTW) using the propensity scores with the same variables for adjustments. The stabilized average treatment effect weight was used for IPTW analysis, which allowed us to maintain the cohort size of the original data and provided a more accurate interval estimate of the variance of the main effect compared with the non-stabilized IPTW.<sup>19</sup>

Two-sided  $P < 0.05$  was considered statistically significant. All analyses were performed using Stata 17 (StataCorp, College Station, TX, USA).

### Ethics Statement

The specific study plan for this study was approved by the Ethics Committee of the Japanese Red Cross Toyota College of Nursing, Aichi, Japan (Institutional Study No. 2006; Principal Investigator: Nagaharu Fukuma, MD, PhD). This study was approved by the Japanese Association of Cardiac Rehabilitation and the JCS. The JROAD-DPC study was planned in accordance with the World Medical Association's Declaration of Helsinki and approved by the Institutional Review Board of the National Cerebral and Cardiovascular Center (NCVC), Osaka, Japan, which waived

**Table 3. PSM (CABG and Valve Surgery)**

|                                 | CABG          |               |         |          |               |               |         |          |
|---------------------------------|---------------|---------------|---------|----------|---------------|---------------|---------|----------|
|                                 | Before PSM    |               |         |          | After PSM     |               |         |          |
|                                 | Early CR      |               | P value | Std diff | Early CR      |               | P value | Std diff |
|                                 | No            | Yes           |         |          | No            | Yes           |         |          |
| <b>No. patients</b>             | 20,472        | 22,300        |         |          | 17,550        | 17,550        |         |          |
| <b>Age (years)</b>              | 71 [64–77]    | 71 [64–77]    | 0.48    | 0.011    | 71 [64–77]    | 70 [63–77]    | <0.001  | 0.045    |
| <b>Female sex</b>               | 5,017 (24.5)  | 5,067 (22.7)  | <0.001  | 0.042    | 4,145 (23.6)  | 4,585 (26.1)  | <0.001  | 0.058    |
| <b>BMI (kg/m<sup>2</sup>)</b>   |               |               |         |          |               |               |         |          |
| <18.5                           | 1,149 (5.6)   | 1,131 (5.1)   | 0.014   | 0.022    | 933 (5.3)     | 960 (5.5)     | 0.93    | 0.003    |
| 18.5–24.9                       | 12,650 (61.8) | 13,800 (61.9) |         |          | 10,786 (61.5) | 10,779 (61.4) |         |          |
| 25.0–29.9                       | 5,576 (27.2)  | 6,250 (28.0)  |         |          | 4,881 (27.8)  | 4,871 (27.8)  |         |          |
| ≥30.0                           | 1,097 (5.4)   | 1,119 (5.0)   |         |          | 950 (5.4)     | 940 (5.4)     |         |          |
| <b>CCI</b>                      | 2 (1, 3)      | 2 (1, 3)      | <0.001  | 0.105    | 2 (1, 3)      | 2 (1, 3)      | <0.001  | 0.052    |
| <b>BIS at admission</b>         |               |               |         |          |               |               |         |          |
| ≤90                             | 1,974 (9.6)   | 1,838 (8.2)   | <0.001  | 0.268    | 1,702 (9.7)   | 1,549 (8.8)   | 0.012   | 0.017    |
| >90                             | 14,514 (70.9) | 18,288 (82.0) |         |          | 13,753 (78.4) | 13,828 (78.8) |         |          |
| Missing                         | 3,984 (19.5)  | 2,174 (9.7)   |         |          | 2,095 (11.9)  | 2,173 (12.4)  |         |          |
| <b>Emergency admission (%)</b>  | 6,932 (33.9)  | 4,367 (19.6)  | <0.001  | 0.327    | 4,250 (24.2)  | 4,366 (24.9)  | 0.15    | 0.015    |
| <b>CV risk factors</b>          |               |               |         |          |               |               |         |          |
| Heart failure                   | 8,176 (39.9)  | 7,578 (34.0)  | <0.001  | 0.124    | 6,515 (37.1)  | 7,168 (40.8)  | <0.001  | 0.076    |
| Aortic stenosis                 | 3,352 (16.4)  | 3,567 (16.0)  | 0.29    | 0.01     | 2,970 (16.9)  | 3,261 (18.6)  | <0.001  | 0.043    |
| Endocarditis                    | 74 (0.4)      | 69 (0.3)      | 0.35    | 0.009    | 61 (0.3)      | 55 (0.3)      | 0.58    | 0.006    |
| <b>Comorbidities (%)</b>        |               |               |         |          |               |               |         |          |
| CKD or HD                       | 3,836 (18.7)  | 3,202 (14.4)  | <0.001  | 0.118    | 3,021 (17.2)  | 3,197 (18.2)  | 0.014   | 0.026    |
| CVD                             | 462 (2.3)     | 528 (2.4)     | 0.45    | 0.007    | 422 (2.4)     | 430 (2.4)     | 0.78    | 0.003    |
| PAD                             | 1,158 (5.7)   | 1,485 (6.7)   | <0.001  | 0.042    | 1,083 (6.2)   | 916 (5.2)     | <0.001  | 0.041    |
| COPD                            | 397 (1.9)     | 511 (2.3)     | 0.012   | 0.024    | 369 (2.1)     | 302 (1.7)     | 0.009   | 0.028    |
| <b>Diabetes</b>                 | 6,881 (33.6)  | 7,777 (34.9)  | 0.006   | 0.027    | 6,012 (34.3)  | 5,521 (31.4)  | <0.001  | 0.024    |
| <b>Medications (%)</b>          |               |               |         |          |               |               |         |          |
| HG agents                       | 6,881 (33.6)  | 7,777 (34.9)  | 0.006   | 0.027    | 6,012 (34.3)  | 5,521 (31.4)  | <0.001  | 0.024    |
| Digoxin                         | 499 (2.4)     | 536 (2.4)     | 0.82    | 0.002    | 444 (2.5)     | 458 (2.6)     | 0.38    | 0.009    |
| Catecholamine                   | 1,313 (6.4)   | 629 (2.8)     | <0.001  | 0.172    | 677 (3.9)     | 628 (3.6)     | 0.17    | 0.015    |
| <b>Device use before OP (%)</b> |               |               |         |          |               |               |         |          |
| IABP                            | 1,762 (8.6)   | 760 (3.4)     | <0.001  | 0.22     | 821 (4.7)     | 759 (4.3)     | 0.32    | 0.011    |
| ECMO                            | 33 (0.2)      | 5 (<1)        | <0.001  | 0.046    | 6 (<1)        | 4 (<1)        | 0.53    | 0.007    |

Unless indicated otherwise, data are given as n (%) or the median [interquartile range]. CR, cardiac rehabilitation; OP, operation; PSM, propensity score matching. Other abbreviations as in Table 1.

(Table 3 continued the next page.)

the requirement for individual informed consent according to the “opt-out” principle. Each participating hospital anonymized each patient’s identity in the DPC/PDPS claim data by a code change equation and submitted the DPC/PDPS claim data to the NCVC.

## Results

### Patients (Figure 1; Table 1)

From April 2012 to March 2018, 220,122 patients who had undergone cardiac and thoracic aortic surgery were registered in the DPC database. After exclusion criteria had been applied, 42,772 patients who underwent CABG, 47,490 patients who underwent valve surgery, 40,225 patients who underwent aortic surgery, and 1,557 who underwent other types of cardiovascular surgery were included in this study.

For all surgical procedures, the mean age of patients was approximately 70 years, and the percentage of females

undergoing each surgical procedure was low (23.6% and 29.1% for CABG and aortic surgery, respectively). The BIS at admission, a method of assessing ADL, was ≤80 in 8.9%, 8.3%, 6.0%, and 10.2% of patients undergoing CABG, valve surgery, aortic surgery, and other surgery, respectively. The BIS was >80 in 76.7%, 85.6%, 70.0%, and 78.0% of patients undergoing CABG, valve surgery, aortic surgery, and other surgery, respectively. At admission, the Japan Coma Scale was documented for 93.8% of patients who underwent aortic surgery and for >95% of patients who underwent other surgeries. Dizziness, somnolence, and coma were higher among those undergoing aortic surgery (3.8%) than among those undergoing CABG (1.7%), valve surgery (1.1%), and others (2.0%). Diagnoses of heart failure and atrial fibrillation were most common among patients who underwent valve surgery (52.1%). The number of hospital beds was about 30% for 301–600 beds and 60% for 601 beds or more in each surgical procedure.



|                          | Valve surgery |               |         |          |               |               |         |          |
|--------------------------|---------------|---------------|---------|----------|---------------|---------------|---------|----------|
|                          | Before PSM    |               |         |          | After PSM     |               |         |          |
|                          | Early CR      |               | P value | Std diff | Early CR      |               | P value | Std diff |
|                          | No            | Yes           |         |          | No            | Yes           |         |          |
| No. patients             | 20,457        | 27,033        |         |          | 19,349        | 19,349        |         |          |
| Age (years)              | 72 [64–78]    | 72 [65–78]    | 0.17    | 0.02     | 72 [64–78]    | 71 [63–78]    | <0.001  | 0.065    |
| Female sex               | 9,325 (45.6)  | 12,248 (45.3) | 0.55    | 0.006    | 8,855 (45.8)  | 9,272 (47.9)  | <0.001  | 0.043    |
| BMI (kg/m <sup>2</sup> ) |               |               |         |          |               |               |         |          |
| <18.5                    | 2,361 (11.5)  | 2,916 (10.8)  | 0.034   | 0.035    | 2,165 (11.2)  | 2,384 (12.3)  | <0.001  | 0.039    |
| 18.5–24.9                | 13,260 (64.8) | 17,565 (65.0) |         |          | 12,573 (65.0) | 12,661 (65.4) |         |          |
| 25.0–29.9                | 4,079 (19.9)  | 5,570 (20.6)  |         |          | 3,897 (20.1)  | 3,653 (18.9)  |         |          |
| ≥30.0                    | 757 (3.7)     | 982 (3.6)     |         |          | 714 (3.7)     | 651 (3.4)     |         |          |
| CCI                      | 1 (1, 2)      | 1 (1, 2)      | <0.001  | 0.118    | 1 (1, 2)      | 1 (1, 2)      | <0.001  | 0.01     |
| BIS at admission         |               |               |         |          |               |               |         |          |
| ≤90                      | 1,993 (9.7)   | 1,967 (7.3)   | <0.001  | 0.143    | 1,806 (9.3)   | 1,503 (7.8)   | <0.001  | 0.009    |
| >90                      | 16,781 (82.0) | 23,880 (88.3) |         |          | 16,375 (84.6) | 16,674 (86.2) |         |          |
| Missing                  | 1,683 (8.2)   | 1,186 (4.4)   |         |          | 1,168 (6.0)   | 1,172 (6.1)   |         |          |
| Emergency admission (%)  | 3,134 (15.3)  | 2,205 (8.2)   | <0.001  | 0.224    | 2,207 (11.4)  | 2,204 (11.4)  | 0.96    | 0        |
| CV risk factors          |               |               |         |          |               |               |         |          |
| Heart failure            | 11,103 (54.3) | 13,631 (50.4) | <0.001  | 0.077    | 10,291 (53.2) | 11,713 (60.5) | <0.001  | 0.149    |
| Aortic stenosis          | 12,110 (59.2) | 16,371 (60.6) | 0.003   | 0.028    | 11,534 (59.6) | 10,722 (55.4) | <0.001  | 0.085    |
| Endocarditis             | 874 (4.3)     | 677 (2.5)     | <0.001  | 0.098    | 638 (3.3)     | 673 (3.5)     | 0.45    | 0.01     |
| Comorbidities (%)        |               |               |         |          |               |               |         |          |
| CKD or HD                | 3,038 (14.9)  | 2,813 (10.4)  | <0.001  | 0.134    | 2,644 (13.7)  | 2,813 (14.5)  | 0.014   | 0.025    |
| CVD                      | 510 (2.5)     | 569 (2.1)     | 0.005   | 0.026    | 461 (2.4)     | 515 (2.7)     | 0.080   | 0.018    |
| PAD                      | 474 (2.3)     | 743 (2.7)     | 0.003   | 0.027    | 460 (2.4)     | 378 (2.0)     | 0.004   | 0.029    |
| COPD                     | 403 (2.0)     | 607 (2.2)     | 0.039   | 0.019    | 389 (2.0)     | 301 (1.6)     | <0.001  | 0.034    |
| Diabetes                 | 3,177 (15.5)  | 3,945 (14.6)  | 0.005   | 0.026    | 2,930 (15.1)  | 3,101 (16.0)  | 0.017   | 0.024    |
| Medications (%)          |               |               |         |          |               |               |         |          |
| HG agents                | 3,177 (15.5)  | 3,945 (14.6)  | 0.005   | 0.026    | 2,930 (15.1)  | 3,101 (16.0)  | 0.017   | 0.024    |
| Digoxin                  | 1,222 (6.0)   | 1,559 (5.8)   | 0.34    | 0.009    | 1,163 (6.0)   | 1,302 (6.7)   | 0.004   | 0.029    |
| Catecholamine            | 1,088 (5.3)   | 648 (2.4)     | <0.001  | 0.152    | 691 (3.6)     | 647 (3.3)     | 0.42    | 0.008    |
| Device use before OP (%) |               |               |         |          |               |               |         |          |
| IABP                     | 350 (1.7)     | 106 (0.4)     | <0.001  | 0.13     | 118 (0.6)     | 105 (0.5)     | 0.38    | 0.009    |
| ECMO                     | 34 (0.2)      | 5 (<1)        | <0.001  | 0.049    | 9 (<1)        | 54 (<1)       | 0.017   | 0.014    |

### Outcomes for the E-CR and Non-E-CR Groups (Table 2)

In this study included patients were categorized into 2 groups (E-CR and non-E-CR) by the median number of days after open surgery when CR was started. Analysis of the data revealed that CR was started a median of 1 day (IQR 1–3 days) after open surgery, and so E-CR in this study was defined as CR starting within 1 day after surgery.

Of all patients who participated in CR after surgery, E-CR was performed in 52.1% (22,300/42,772) of patients who had undergone CABG, 56.9% (27,033/47,490) of those who had undergone valve surgery, 47.4% (19,085/40,225) of those who had undergone aortic surgery, and 54.1% (842/1,557) of those who had undergone other cardiovascular surgery (Figure 2).

In-hospital death rates were significantly lower in the E-CR than non-E-CR group for all surgical procedures (1.5% vs. 3.4%, respectively, for CABG; 1.5% vs. 3.4% respectively, for valve surgery; 2.1% vs. 4.5%, respectively, for aortic surgery; and 1.4% vs. 4.1%, respectively, for other cardiovascular surgery). The BIS at discharge, which was examined for all patients and for patients who survived, was significantly higher in the E-CR than non-E-CR

group for all surgical procedures. The length of hospital stay was shorter and hospitalization costs were lower in the E-CR than non-E-CR group for all surgical procedures.

### Outcomes for the E-CR and Non-E-CR Groups by Type of Surgery (PSM) (Tables 3–5)

Adjusted odds ratios for in-hospital death were 0.37 (95% confidence interval [CI] 0.31–0.43) for CABG, 0.41 (95% CI 0.35–0.48) for valve surgery, 0.46 (95% CI 0.39–0.53) for aortic surgery, and 0.26 (95% CI 0.11–0.63) for other types of cardiovascular surgery. In-hospital mortality was lower in the E-CR than non-E-CR group. The BIS at discharge was higher in the E-CR than non-E-CR group. The regression coefficient on the logit scale ( $\beta$ ) for BIS at discharge was 3.9 (95% CI 3.4–4.3) for CABG, 3.9 (95% CI 3.5–4.4) for valve surgery, 4.3 (95% CI 3.7–4.8) for aortic surgery, and 6.1 (95% CI 3.7–8.5) for other types of cardiovascular surgery. Of note, the length of hospital stay was shorter in the E-CR than non-E-CR group, with  $\beta$  coefficients of –3.8 (95% CI –4.2, –3.4) for CABG, –4.4 (95% CI –4.8, –4.0) for valve surgery, –4.8 (95% CI –5.2, –4.4) for aortic surgery, and –4.4 (95% CI –6.2, –2.6) for other

**Table 4. PSM (Aortic Surgery and Other CV Surgery)**

|                                 | Aortic surgery |               |         |          |               |               |         |          |
|---------------------------------|----------------|---------------|---------|----------|---------------|---------------|---------|----------|
|                                 | Before PSM     |               |         |          | After PSM     |               |         |          |
|                                 | Early CR       |               | P value | Std diff | Early CR      |               | P value | Std diff |
|                                 | No             | Yes           |         |          | No            | Yes           |         |          |
| <b>No. patients</b>             | 21,140         | 19,085        |         |          | 15,420        | 15,420        |         |          |
| <b>Age (years)</b>              | 70 [63–77]     | 71 [64–77]    | <0.001  | 0.07     | 71 [64–77]    | 69 [62–76]    | <0.001  | 0.09     |
| <b>Female sex</b>               | 6,691 (31.7)   | 5,012 (26.3)  | <0.001  | 0.119    | 4,309 (27.9)  | 4,625 (30.0)  | <0.001  | 0.045    |
| <b>BMI (kg/m<sup>2</sup>)</b>   |                |               |         |          |               |               |         |          |
| <18.5                           | 1,652 (7.8)    | 1,336 (7.0)   | <0.001  | 0.011    | 1,140 (7.4)   | 1,028 (6.7)   | <0.001  | 0.066    |
| 18.5–24.9                       | 12,865 (60.9)  | 11,908 (62.4) |         |          | 9,494 (61.6)  | 9,175 (59.5)  |         |          |
| 25.0–29.9                       | 5,493 (26.0)   | 5,058 (26.5)  |         |          | 4,067 (26.4)  | 4,447 (28.8)  |         |          |
| ≥30.0                           | 1,130 (5.3)    | 783 (4.1)     |         |          | 719 (4.7)     | 770 (5.0)     |         |          |
| <b>CCI</b>                      | 2 (1, 2)       | 2 (1, 2)      | <0.001  | 0.047    | 2 (1, 2)      | 2 (1, 2)      | 0.017   | 0.027    |
| <b>BIS at admission</b>         |                |               |         |          |               |               |         |          |
| ≤90                             | 1,392 (6.6)    | 1,015 (5.3)   | <0.001  | 0.376    | 958 (6.2)     | 814 (5.3)     | 0.002   | 0.011    |
| >90                             | 13,073 (61.8)  | 15,101 (79.1) |         |          | 11,549 (74.9) | 11,645 (75.5) |         |          |
| Missing                         | 6,675 (31.6)   | 2,969 (15.6)  |         |          | 2,913 (18.9)  | 2,961 (19.2)  |         |          |
| <b>Emergency admission (%)</b>  | 9,819 (46.4)   | 4,319 (22.6)  | <0.001  | 0.517    | 4,309 (27.9)  | 4,319 (28.0)  | 0.90    | 0.001    |
| <b>CV risk factors</b>          |                |               |         |          |               |               |         |          |
| Heart failure                   | 5,558 (26.3)   | 4,216 (22.1)  | <0.001  | 0.098    | 3,814 (24.7)  | 4,216 (27.3)  | <0.001  | 0.059    |
| Aortic stenosis                 | 4,345 (20.6)   | 4,378 (22.9)  | <0.001  | 0.058    | 3,506 (22.7)  | 3,321 (21.5)  | 0.0011  | 0.029    |
| Endocarditis                    | 104 (0.5)      | 87 (0.5)      | 0.60    | 0.005    | 71 (0.5)      | 67 (0.4)      | 0.73    | 0.004    |
| <b>Comorbidities (%)</b>        |                |               |         |          |               |               |         |          |
| CKD or HD                       | 1,930 (9.1)    | 1,260 (6.6)   | <0.001  | 0.094    | 1,216 (7.9)   | 1,260 (8.2)   | 0.36    | 0.01     |
| CVD                             | 594 (2.8)      | 497 (2.6)     | 0.20    | 0.013    | 415 (2.7)     | 475 (3.1)     | 0.041   | 0.023    |
| PAD                             | 737 (3.5)      | 901 (4.7)     | <0.001  | 0.062    | 663 (4.3)     | 482 (3.1)     | <0.001  | 0.062    |
| COPD                            | 713 (3.4)      | 782 (4.1)     | <0.001  | 0.038    | 590 (3.8)     | 528 (3.4)     | 0.059   | 0.022    |
| Diabetes mellitus               | 1,760 (8.3)    | 1,657 (8.7)   | 0.20    | 0.013    | 1,344 (8.7)   | 1,572 (10.2)  | <0.001  | 0.021    |
| <b>Medications (%)</b>          |                |               |         |          |               |               |         |          |
| HG agents                       | 1,760 (8.3)    | 1,657 (8.7)   | 0.20    | 0.013    | 1,344 (8.7)   | 1,572 (10.2)  | <0.001  | 0.021    |
| Digoxin                         | 431 (2.0)      | 330 (1.7)     | 0.023   | 0.023    | 303 (2.0)     | 330 (2.1)     | 0.28    | 0.012    |
| Catecholamine                   | 335 (1.6)      | 143 (0.7)     | <0.001  | 0.078    | 151 (1.0)     | 143 (0.9)     | 0.64    | 0.005    |
| <b>Device use before OP (%)</b> |                |               |         |          |               |               |         |          |
| IABP                            | 16 (0.1)       | 4 (<1)        | 0.014   | 0.025    | 4 (<1)        | 4 (<1)        | 1.00    | 0        |
| ECMO                            | 2 (<1)         | 0 (0.0)       | 0.18    | 0.014    | 0 (0.0)       | 0 (0.0)       | –       | –        |

Unless indicated otherwise, data are given as n (%) or the median [interquartile range]. Abbreviations as in Tables 1,3.

(Table 4 continued the next page.)

types of cardiovascular surgery. Hospitalization costs were lower for patients in the E-CR than non-E-CR group.

Sensitivity analysis was conducted excluding patients who received postoperative mechanical support. All end-points were significantly better for patients in the E-CR than non-E-CR group (all  $P < 0.001$ ), with no difference in results when patients receiving postoperative mechanical support were included (Supplementary Table).

## Discussion

Based on the results of the present study, of all patients who participated in CR after surgery, E-CR was performed 52.1%, 56.9%, 47.4%, and 54.1% of those who underwent CABG, valve surgery, aortic surgery, and other cardiovascular surgery, respectively. Furthermore, after PSM, the E-CR group showed superior results in terms of the in-hospital death rate, BIS at discharge, length of hospital stay, and hospitalization costs. These results were demonstrated consistently for all surgical procedures, suggesting

the need to further recommend the introduction of E-CR in the future. In the present study, patients were categorized into 2 groups using the median number of postoperative days when CR was started. CR after open surgery was started a median of 1 day after surgery, so E-CR in the present study was defined as CR starting within 1 day after surgery. Currently, there is no clear definition of E-CR in terms of days postoperatively. In previous reports, E-CR has been defined as starting from 1 to 3 days after surgery,<sup>20–22</sup> and the meta-analysis by Kanejima et al reported that CR after surgery was started by postoperative Day 1 or 2 in all studies.<sup>21</sup> Based on the results of the present study, there is no problem in terms of safety, even if CR is performed within 1 day of surgery, and the efficacy of CR is clear.

The results of the present study are in line with previous findings regarding CR. For example, Ohbe et al reported on the implementation of E-CR within 3 days after CABG in 30,568 patients using DPC data.<sup>20</sup> In that study, 43% of patients underwent E-CR, and the BIS at discharge was



|                                 | Other      |            |         |          |               |              |         |          |
|---------------------------------|------------|------------|---------|----------|---------------|--------------|---------|----------|
|                                 | Before PSM |            |         |          | After PSM     |              |         |          |
|                                 | Early CR   |            | P value | Std diff | Early CR      |              | P value | Std diff |
|                                 | No         | Yes        |         |          | No            | Yes          |         |          |
| <b>No. patients</b>             | 715        | 842        |         |          | 641           | 641          |         |          |
| <b>Age (years)</b>              | 68 [57–75] | 69 [61–76] | 0.007   | 0.149    | 68 [58–75]    | 67 [58–74]   | 0.35    | 0.041    |
| <b>Female sex</b>               | 394 (55.1) | 470 (55.8) | 0.78    | 0.014    | 361 (56.3)    | 342 (53.4)   | 0.29    | 0.06     |
| <b>BMI (kg/m<sup>2</sup>)</b>   |            |            |         |          |               |              |         |          |
| <18.5                           | 72 (10.1)  | 77 (9.1)   | 0.080   | 0.085    | 62 (9.7)      | 49 (7.6)     | 0.15    | 0.01     |
| 18.5–24.9                       | 444 (62.1) | 563 (66.9) |         |          | 411 (64.1)    | 422 (65.8)   |         |          |
| 25.0–29.9                       | 160 (22.4) | 175 (20.8) |         |          | 132 (20.6)    | 147 (22.9)   |         |          |
| ≥30.0                           | 39 (5.5)   | 27 (3.2)   |         |          | 36 (5.6)      | 23 (3.6)     |         |          |
| <b>CCI</b>                      | 1 (1, 2)   | 1 (1, 2)   | 0.60    | 0.012    | 1 (1, 2)      | 1 (1, 2)     | 0.25    | 0.028    |
| <b>BIS at admission</b>         |            |            |         |          |               |              |         |          |
| ≤90                             | 90 (12.6)  | 69 (8.2)   | <0.001  | 0.143    | 1,806 (9.3)   | 1,503 (7.8)  | <0.001  | 0.009    |
| >90                             | 520 (72.7) | 694 (82.4) |         |          | 16,375 (84.6) | 1,667 (86.2) |         |          |
| Missing                         | 105 (14.7) | 79 (9.4)   |         |          | 1,168 (6.0)   | 1,172 (6.1)  |         |          |
| <b>Emergency admission (%)</b>  | 251 (35.1) | 200 (23.8) | <0.001  | 0.251    | 180 (28.1)    | 197 (30.7)   | 0.30    | 0.058    |
| <b>CV risk factors</b>          |            |            |         |          |               |              |         |          |
| Heart failure                   | 295 (41.3) | 307 (36.5) | 0.053   | 0.098    | 250 (39.0)    | 271 (42.3)   | 0.23    | 0.067    |
| Aortic stenosis                 | 27 (3.8)   | 39 (4.6)   | 0.40    | 0.043    | 26 (4.1)      | 21 (3.3)     | 0.46    | 0.041    |
| Endocarditis                    | 8 (1.1)    | 9 (1.1)    | 0.92    | 0.005    | 7 (1.1)       | 6 (0.9)      | 0.78    | 0.016    |
| <b>Comorbidities (%)</b>        |            |            |         |          |               |              |         |          |
| CKD or HD                       | 42 (5.9)   | 58 (6.9)   | 0.42    | 0.041    | 38 (5.9)      | 35 (5.4)     | 0.72    | 0.02     |
| CVD                             | 33 (4.6)   | 46 (5.5)   | 0.45    | 0.039    | 33 (5.1)      | 23 (3.6)     | 0.17    | 0.076    |
| PAD                             | 11 (1.5)   | 30 (3.6)   | 0.013   | 0.129    | 10 (1.6)      | 10 (1.6)     | 1.00    | 0        |
| COPD                            | 18 (2.5)   | 20 (2.4)   | 0.86    | 0.009    | 18 (2.8)      | 15 (2.3)     | 0.60    | 0.029    |
| Diabetes mellitus               | 98 (13.7)  | 116 (13.8) | 0.97    | 0.002    | 90 (14.0)     | 91 (14.2)    | 0.94    | 0.021    |
| <b>Medications (%)</b>          |            |            |         |          |               |              |         |          |
| HG agents                       | 98 (13.7)  | 116 (13.8) | 0.97    | 0.002    | 90 (14.0)     | 91 (14.2)    | 0.94    | 0.021    |
| Digoxin                         | 31 (4.3)   | 28 (3.3)   | 0.30    | 0.053    | 25 (3.9)      | 25 (3.9)     | 1.00    | 0        |
| Catecholamine                   | 18 (2.5)   | 14 (1.7)   | 0.24    | 0.06     | 11 (1.7)      | 12 (1.9)     | 0.83    | 0.012    |
| <b>Device use before OP (%)</b> |            |            |         |          |               |              |         |          |
| IABP                            | 2 (0.3)    | 0 (0.0)    | 0.12    | 0.075    | 0 (0.0)       | 0 (0.0)      | –       | –        |
| ECMO                            | 7 (1.0)    | 3 (0.4)    | 0.13    | 0.076    | 4 (0.6)       | 3 (0.5)      | 0.70    | 0.021    |

significantly higher in those who had undertaken E-CR compared with normal CR, and in-hospital mortality, total hospitalization costs, length of ICU stay, and hospital stay were significantly lower in the E-CR group.<sup>20</sup> Moreover, in a meta-analysis, Kanejima et al reported that E-CR intervention within 2 days after cardiac surgery improved 6-min walking distance by 54 m.<sup>21</sup>

A Japanese multicenter study examining the efficacy of outpatient CR after CABG (the J-REHAB CABG study) in 346 patients who were followed up for 3.5 years reported that the rates of a major adverse cardiac events, all-cause death, and rehospitalization for a cardiac event were significantly lower in the active than non-active CR group.<sup>23</sup> However, although many studies have reported on CR after CABG, few studies have been conducted into the effects of CR on outcomes for other types of cardiac surgery. In the US, a study of 16,935 patients who had undergone valve surgery reported that the percentage of patients registered for CR was low, at 43.2%.<sup>24</sup> Despite this low percentage, those who participated in CR had reduced hospitalization and mortality rates within 1 year after discharge, suggesting that CR is important not only after

CABG, but also after valve surgery.<sup>24</sup> The results of the present study demonstrate the efficacy of E-CR not only for CABG, but also for valve and aortic surgery.

Regarding E-CR and age, Itagaki et al conducted a multicenter retrospective study involving 8 facilities, in which 523 older patients who had undergone cardiac surgery and started CR 1 day postoperatively were examined.<sup>22</sup> In that study, walking speed decreased in 17% of patients. The authors concluded that further interventional research on rehabilitation before and after cardiac surgery for older patients may help overcome the decline in physical functioning.<sup>22</sup> The mean age of participants in the present study was 70 years; hence, it is possible that the importance of E-CR for older adults can be demonstrated by later conducting subanalyses of the results for older participants. In addition, it may be necessary to conduct a prospective study in which cardiopulmonary exercise testing (i.e., 6-min walking distance and muscle strength assessment) is performed. Because exercise tolerance and lower extremity muscle strength decrease after 10 days of bed rest in healthy older adults,<sup>25</sup> introducing E-CR is all the more necessary the older the patient is. The results of numerous studies

**Table 5. Main Results in Patients Undergoing CABG, Valve Surgery, Aortic Surgery or Other CV Surgery**

|   | CABG                   |         | Valve surgery          |         |
|---|------------------------|---------|------------------------|---------|
|   | OR or $\beta$ (95% CI) | P value | OR or $\beta$ (95% CI) | P value |
| <b>Propensity score matching</b>                  |                        |         |                        |         |
| In-hospital death (OR)                            | 0.37 (0.31, 0.43)      | <0.001  | 0.41 (0.35, 0.48)      | <0.001  |
| BIS at discharge ( $\beta$ )                      | 3.9 (3.4, 4.3)         | <0.001  | 3.9 (3.5, 4.4)         | <0.001  |
| Length of hospital stay ( $\beta$ )               | -3.8 (-4.2, -3.4)      | <0.001  | -4.4 (-4.8, -4.0)      | <0.001  |
| Hospitalization costs ( $\beta$ )                 | -0.72 (-0.77, -0.67)   | <0.001  | -0.68 (-0.72, -0.63)   | <0.001  |
| <b>Mixed-model regression analysis</b>            |                        |         |                        |         |
| In-hospital death (OR)                            | 0.42 (0.36, 0.49)      | <0.001  | 0.45 (0.38, 0.52)      | <0.001  |
| BIS at discharge ( $\beta$ )                      |                        |         |                        |         |
| All   | 3.3 (2.9, 3.7)         | <0.001  | 3.2 (2.8, 3.6)         | <0.001  |
| Discharged alive                                  | 1.3 (1.0, 1.6)         | <0.001  | 1.3 (1.1, 1.6)         | <0.001  |
| Length of hospital stay ( $\beta$ )               | -3.5 (-3.9, -3.2)      | <0.001  | -3.8 (-4.1, -3.4)      | <0.001  |
| Hospitalization costs ( $\beta$ )                 | -0.68 (-0.72, -0.64)   | <0.001  | -0.57 (-0.61, -0.53)   | <0.001  |
| <b>Inverse probability of treatment weighting</b> |                        |         |                        |         |
| In-hospital death (OR)                            | 0.65 (0.56, 0.75)      | <0.001  | 0.62 (0.54, 0.70)      | <0.001  |
| BIS at discharge ( $\beta$ )                      | 2.0 (1.6, 2.4)         | <0.001  | 2.1 (1.8, 2.4)         | <0.001  |
| Length of hospital stay ( $\beta$ )               | -3.1 (-3.4, -2.7)      | <0.001  | -3.1 (-3.5, -2.8)      | <0.001  |
| Hospitalization costs ( $\beta$ )                 | -0.47 (-0.50, -0.43)   | <0.001  | -0.42 (-0.46, -0.39)   | <0.001  |

|   | Aortic surgery         |         | Other                  |         |
|---|------------------------|---------|------------------------|---------|
|   | OR or $\beta$ (95% CI) | P value | OR or $\beta$ (95% CI) | P value |
| <b>Propensity score matching</b>                  |                        |         |                        |         |
| In-hospital death (OR)                            | 0.46 (0.39, 0.53)      | <0.001  | 0.26 (0.11, 0.63)      | <0.001  |
| BIS at discharge ( $\beta$ )                      | 4.3 (3.7, 4.8)         | <0.001  | 6.1 (3.7, 8.5)         | <0.001  |
| Length of hospital stay ( $\beta$ )               | -4.8 (-5.2, -4.4)      | <0.001  | -4.4 (-6.2, -2.6)      | <0.001  |
| Hospitalization costs ( $\beta$ )                 | -0.93 (-1.00, -0.86)   | <0.001  | -0.60 (-0.79, -0.42)   | <0.001  |
| <b>Mixed-model regression analysis</b>            |                        |         |                        |         |
| In-hospital death (OR)                            | 0.48 (0.42, 0.55)      | <0.001  | 0.32 (0.15, 0.70)      | <0.001  |
| BIS at discharge ( $\beta$ )                      |                        |         |                        |         |
| All   | 3.6 (3.1, 4.0)         | <0.001  | 5.0 (2.9, 7.1)         | <0.001  |
| Discharged alive                                  | 1.6 (1.3, 1.9)         | <0.001  | 2.7 (1.2, 4.2)         | <0.001  |
| Length of hospital stay ( $\beta$ )               | -4.3 (-4.7, -3.9)      | <0.001  | -3.9 (-5.5, -2.3)      | <0.001  |
| Hospitalization costs ( $\beta$ )                 | -0.83 (-0.88, -0.77)   | <0.001  | -0.53 (-0.70, -0.36)   | <0.001  |
| <b>Inverse probability of treatment weighting</b> |                        |         |                        |         |
| In-hospital death (OR)                            | 0.68 (0.60, 0.77)      | <0.001  | 0.40 (0.20, 0.80)      | <0.001  |
| BIS at discharge ( $\beta$ )                      | 2.5 (2.1, 3.0)         | <0.001  | 4.5 (2.5, 6.6)         | <0.001  |
| Length of hospital stay ( $\beta$ )               | -4.3 (-4.7, -3.9)      | <0.001  | -5.0 (-6.6, -3.4)      | <0.001  |
| Hospitalization costs ( $\beta$ )                 | -0.76 (-0.81, -0.70)   | <0.001  | -0.67 (-0.84, -0.50)   | <0.001  |

CI, confidence interval; OR, odds ratio. Other abbreviations as in Table 1.

have shown that CR in elderly patients with heart diseases can improve exercise tolerance and QOL,<sup>26,27</sup> and there is an urgent need to conduct studies in the setting of cardiac surgery, which is performed in many older adults.

There is less evidence for CR in terms of aortic than cardiac procedures. In the present study, the results of E-CR after aortic surgery were comparable to those after CABG and valve surgery. However, the rate of E-CR after aortic surgery was 46.2%, which was lower than after CABG or valve surgery (51.4% and 56.0%, respectively). Possible reasons for this include: (1) the higher frequency of postoperative complications (cerebrovascular disease, respiratory complications, acute renal failure, paraplegia) following aortic surgery than after CABG or valve surgery;

(2) the higher number of patients in which cranial nerve deficit is observed preoperatively, as suggested by results of the Japan Coma Scale at admission, for aortic compared with CABG or valve surgery; and (3) more aortic surgeries are performed as emergency procedures. However, aortic disease is associated with severe arteriosclerosis and, due to the presence of residual lesions, the worsening of chronic conditions is a concern; therefore, there is an increasing need to perform CR under proper guidance. Although not postoperatively examined, we have demonstrated that E-CR for Type B acute aortic dissection at our facility led to a decrease in respiratory complications and delirium rates, thereby clarifying the efficacy of E-CR.<sup>28</sup>

In the present study, E-CR after cardiac surgery showed

excellent outcomes in terms of in-hospital death, BIS at discharge, length of hospital stay, and hospitalization cost for all cardiac surgical procedures. In the future, we plan to perform subanalyses focusing on older adults and patients who have undergone aortic surgery, because E-CR is considered more important in these patient populations, to further clarify the efficacy of E-CR and potential problems that need to be addressed.

### Study Limitations

Because the present study examined information obtained from a database, it has some limitations. First, the detailed content of CR was unclear. Second, this study was based on DPC data, and detailed postoperative data (e.g., postoperative artificial respiration support time, dose of catecholamine, amount of bleeding) could not be evaluated. Third, it is possible that patients who did not take part in E-CR included those who died in an early stage or those for whom CR was not feasible due to postoperative complications. Fourth, the reasons why E-CR could not be performed were unclear. Finally, although E-CR within 1 day postoperatively was effective in the present study, it is not clear how many days postoperatively CR should be started; this will be investigated in the future. Nevertheless, we aim to continue this line of investigation because we consider that a further prospective study will more clearly demonstrate the efficacy of E-CR.

### Conclusions

This study examined the introduction rate of E-CR and its outcomes by procedure for 220,122 patients who underwent major cardiac and thoracic vascular surgery and registered in the DPC between April 2012 and March 2018. Of all patients who participated in CR after surgery, E-CR was performed in 52.1%, 56.9%, 47.4%, and 54.1% of those who underwent CABG, valve surgery, aortic surgery, and other cardiovascular surgery, respectively. The E-CR group showed superior outcomes in terms of in-hospital deaths, BIS at discharge, length of hospital stay, and hospitalization costs compared with the non-E-CR group. These results were demonstrated for all surgical procedures, suggesting the need to further recommend the introduction of E-CR in the future. This study is the first report of E-CR after cardiac surgery using big data, which is very significant.

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### Author Contributions

All authors contributed to the study conception, design, and operations. A.S. wrote the draft of the article. Data analyses and interpreta-

tions were performed by A.S., T.S., K.K., and N.F., whereas K.K., Y.S., M.N., and Y.I. were responsible for the statistical analyses. All authors reviewed drafts of the manuscript. All authors read and approved the final manuscript.

### IRB Information

This study was approved by the Ethics Committee of the Japanese Red Cross Toyota College of Nursing (Reference no. 2006).

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### Supplementary Files

Please find supplementary file(s);  
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